EFFECTS OF OFFSHORE WIND FARMS OPERATIONAL NOISE ON BLUEFIN TUNA BEHAVIOUR

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Abstract: *The number of offshore wind farms is growing up quickly in the lasts years. Several studies about its environmental acoustic impacts have been developed at the same time the industry expands, most of them related to the high level impulsive noise produced during the pile diving process associated to the construction stage. Nevertheless, the study of the impact of the operational noise of turbines is very limited. In this paper we investigate the behavioural response of Bluefin tuna when exposed to the operation noise of a turbine. We analysed tuna reaction in terms of three parameters: depth of the school, swimming pattern and changes in the swimming direction. The experiment was developed in a fixed commercial tuna cage in the Mediterranean Sea. The usual behaviour of Bluefin tuna in captivity conditions was previously analysed using a continuous monitorization. Variations in depth were observed when feeding boat approaches, which could be interpreted as a consequence of the acoustical stimulus. The turbine noise was acoustically characterized, and reproduced using a broad-band underwater source. To monitor tuna behaviour two echosounders and a video system were simultaneously used. When exposed to short duration noise tuna behaviour does not exhibit clear disturbances. Nevertheless, with long duration emission tuna reacted: school reduced the radio of the circular swimming region, moved up to the surface and some individuals were disorientated. Tuna seems to be habituated after several repetitions is short time.*

Keywords: *Offshore wind farm, environmental impact, Bluefin tuna*

1. INTRODUCTION

Offshore wind farms are one of the most promising power sources nowadays, and they are suffering a fast expansion along the coastal areas. Nevertheless, the environmental impacts regarding to the construction and operation of this infrastructures have not been yet completely evaluated, and several studies have been focus on that problem during last years [1]. From the underwater acoustical point of view, most of the studies regard the impact of high intensity pile driving noise produced during the construction period on biological enviroment: benthos, bivalves, marine mammals or fishes, with a wide variety of results, from no evidence of injury or reaction to the immediate death [2,3 and references therein]. Even less is the number of papers concerning the impacts of the operational noise of wind farms, and they consider only a reduced number of target species [Thomsen and therein]. The aim of this work is to contribute to the knowledge of the potential effects of operational noise of wind turbines on the behaviour of Bluefin tuna (*Thunnus thynnus*). Although dramatic consequences as death or physical damage are not expected in this case, the continuous noise associated to the low level long-term operation regime of turbines might affect the behaviour of fishes, which could interfere with feeding processes and migration routes.

Bluefin tuna is a high economic resource and it has been matter of study during lasts years due to the decrease of the stock and the limitation and the control on fishing quotas. In spite of the high economic impact of this specie, the number of studies regarding the effect of underwater sources of noise on them is very limited [4] and only recently the characterization of hearing threshold of similar specie Bluefin tuna (*Thunnus orientalis*) has been dealt with [5]. Tuna form schools that migrate at ocean scales across the Gibraltar strait from Atlantic Ocean to Mediterranean Sea, where their migration routes pass nearby the coastal regions.

In order to investigate the reaction of tuna to the operational turbine noise, Bluefin tuna located in a fixed commercial fattening cage in the Mediterranean Sea were exposed to a noise equivalent to the operational wind turbine noise previously recorded. The animals were continuously monitorized during weeks before the sound exposure using an acoustical and visual system, to ensure that the reactions that could be observed after noise emission were distinguishable from the usual behaviour of the fishes. The behaviour was characterized in terms to three variables: position of fish school along the water column, swimming pattern and changes in swimming direction. As was expected tuna school exhibit different

2. MATERIAL AND METHODS

The acoustical recording system consists of a scientific Biosonics DT-X echosounder, working at 201 kHz and insonificating an angle of 22.5 º at -3 dB. The transducer was located looking up at the surface at 28 meters deep at the bottom of a floating commercial cage of 50 m of diameter, in the middle of one of the radius of the pen. The fattening cage was located in the Mediterranean Sea, in front of L’Ametlla de Mar village at 4000 m from the coast. Together to the transducer was located a video camera protected in a watertight box. During the continuous monitoring study, the system was feeding by external batteries hanging on the cage inside a waterproof box, together with the electronics for controlling the system, data transfer was done by a wifi communication and system was remotely controlled. Tuna school behaviour was continously monitorized along six weeks. During the exposition to the turbine noise, an extra single-beam Knudsen echosounder was installed in the cage to control the part of the school that was out of the region insonificated by the other echosounder to ensure that the distribution and behaviour of tuna has not evident differences along the cage. The video camera was located alongside the measurement echosounder. A scheme of the system is shown in Figure 1.

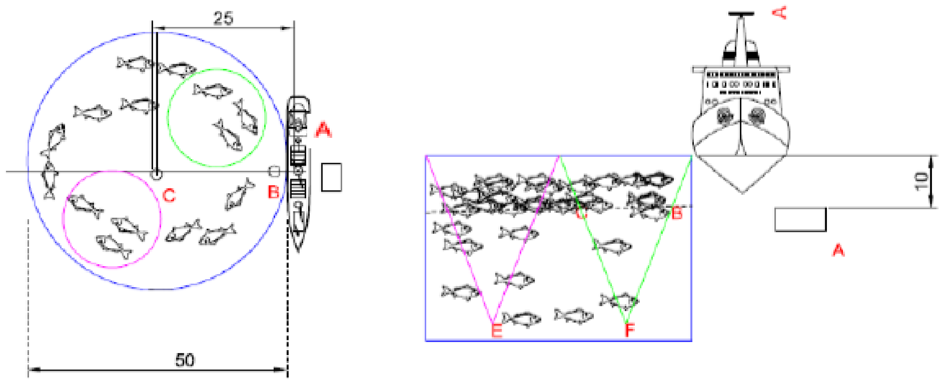

Fig.1. Scheme of the experimental setup: A) Noise generator and control boat. B) Hydrophone at 1 meter distance. C) Hydrophone at 25 m distance. E) Auxiliary echosounder F) Measurement echosounder and camera.

The experiment was designed to test the effect of operational turbine noise on Bluefin tuna behaviour. The noise of a wind turbine was previously recorded 50 meters from the source during 30 seconds and sampled at 350 kHz. The wind farm turbine produces a broad band noise (from 40 to 10000 HZ) with different characteristic peaks at 50 Hz (≈142 dB ref 1 μPa) at 50 meters from the source. A broad-band Data Physics GW350 underwater source property of the Spanish Army was used to reproduce the turbine sound.

3. RESULTS

3.1. Usual behaviour

The behaviour of tuna school was continuously monitored along six weeks during January and February of 2013. The result of monitorization consisted in an amount of 700 hours of acoustic recordings and 150 hours of video. Data were analyzed using software developed specifically for this purpose in Matlab® code.

Tuna school usually swims in a circular pattern covering a large area of the cage, swimming closer to the cage nets. As expected [6], school depth exhibited day/night variations. During the middle of the day the school tends to be closer to the surface, going deeper overnight. This behaviour was observed repeatedly during the period of continuous monitoring, recording an average difference Δ=2.3 meters between day and night depths.

The school also reacts to the feeding boat. Tunas were fed with frozen mackerel blocks were thrown through a tube from the boat and floats in the middle of the cage. When feeding boat arrived and moored beside the cage, before the food was launched, tuna escape from the surface and swim deeper. The school remains far from the surface until the boat departs and then rises up again. Fig. 2 shows the echograms corresponding to the described process, where the distance from cage bottom, *d*, is indicated. This behaviour can be interpreted as related to the feeding boat noise, well as an avoidance movement, well as a feeding manoeuvre. In any case, it seems to be clear that, as expected [4], tuna react to noise, and so they can be affected by the turbine noise we want to test.

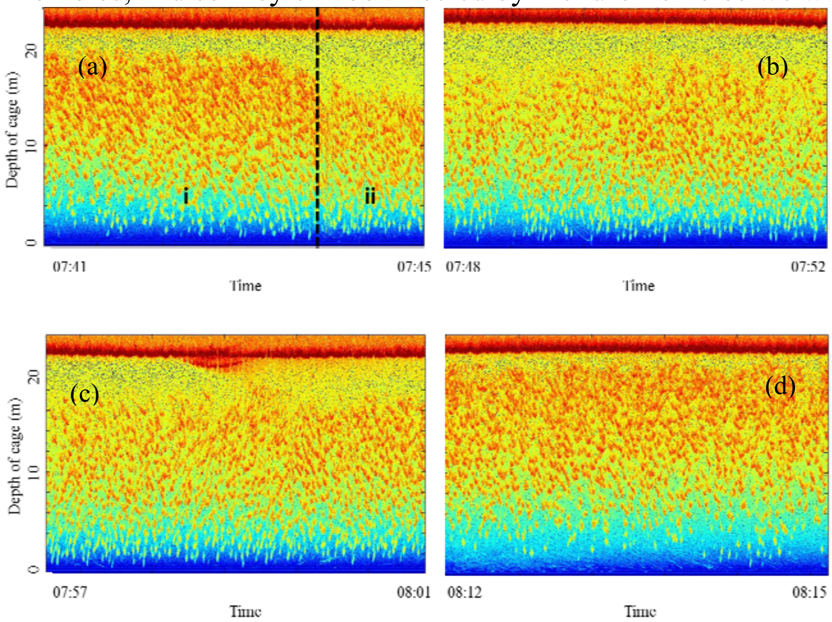

Fig.2. Echograms corresponding to feeding process at 15-01-2013. (a) Boat approaches (dashed line), d_i=11.6m and d_{ii}=9.17 m, (b) Boat moored unloading food block. Tuna going deeper d=9.8m, (c) Food block through the acoustic beam. School still far from the surface d=10.1m, (d) boat departs from the cage and tuna rise again d=12.3m.

3.2. Effect of turbine noise

The noise produced by a turbine was recorded at 50 meters from the source, sampled at 350 KHz. The noise was reproduced using a previously characterized broad-band Data Physics GW350 underwater source. The sound was reproduced, as shown in Fig. 3.

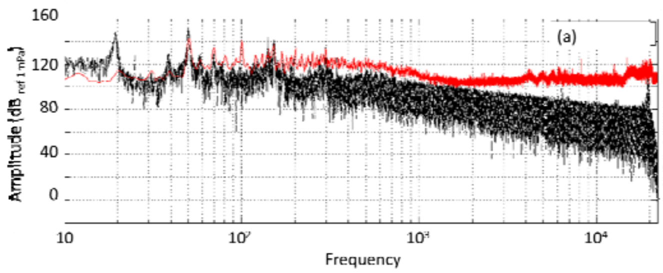

Fig.3. Original recorded turbine emission (black) and reproduced noise used in the experiment (red).

To ensure the health of animals, the experiment was limited to not exceed the usual acoustic levels to which they were subjected tuna. In order to satisfy this requirement, the acoustic environment of the cage was recorded and the maximum level registered, corresponding to the shot of bang stick when tuna are sacrificed determined the maximum sound level of turbine noise emission (maximum SPL~165 dB $_{\text{ref } 1\mu\text{Pa}}$), which corresponds to a turbine working at 6.5 meters. Reaction under short (from ten to fifteen seconds) and long (from ten to fifteen minutes) stimuli were tested. Results can be summarized as follows (Fig.4):

i) Short time emission. First time that tuna were exposed to the short time duration turbine noise, they moved fast to the surface, in a clear avoidance manoeuvre from the noise source. When sound ceased, they recovered the original distribution along the cage. Nevertheless, this behaviour could not be observed again, and tuna did not react any more time to this short time stimulus. It should be note that the time interval between different measurements was very short due to technical limitations.

ii) Long time emission. In this second case, tuna behaviour evidenced the reaction to turbine noise during and after the sound exposure.

-School depth: after some minutes from the beginning of noise emission, school moves up. Tuna remain swimming closer to the surface even when acoustic emission has finished, and only some minutes later recover the original distribution.

-Swim pattern: tuna bunched and swim closer together; they still swim like a school with a circular pattern, but with a smaller radius, and only occupy half part of the cage. It could be observed from the control boat and assessed by data from control echosounder and video camera: almost no tuna was recorded during sound emission

-Disorientation: during the minutes after emission, some specimens swam in opposite direction to the rest of school, which could be interpreted as slight disorientation. Several five minutes intervals were analysed before (ten random intervals) and after (one after any emission) the sound emission. During the intervals previous to the emission, any tuna changed his swimming direction from the school one, nevertheless after long time noise emission, an average of 15 tuna in 5 minutes were registered to swim in opposite direction with higher speed. (We note that we only could register the changes of swimming direction after noise emission, because tuna were out from the visual range of the camera).

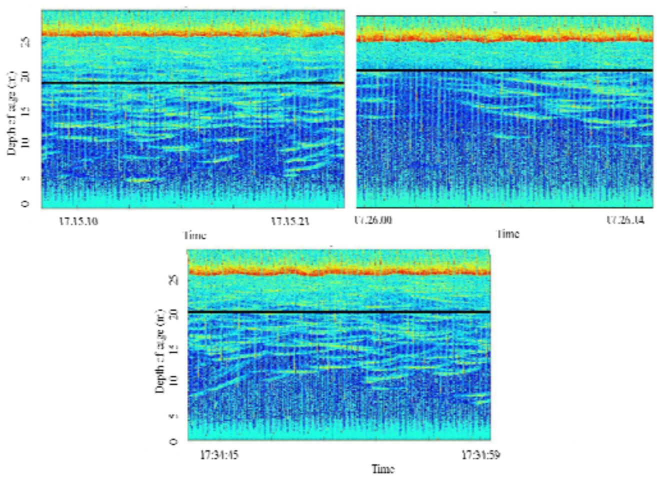

Fig.4. Echograms corresponding to ten minutes noise emission at 17:15h with different positions of school in water column (a) d=19.03 m, (b) d=21.43 m and (c) d=20.13 m (d measured from bottom).

The experiment was developed in absence of shipping in the neighbourhood of the cage (background SPL 110/120 dB $_{\text{ref } 1\mu\text{Pa}}$). Second time that it was repeated, tuna exhibited the same kind of behaviour, but with longer reaction time. Third time, and under noisier conditions, tuna behaviour did not exhibit evident variations, showing a high degree of adaptability to noise.

4. CONCLUSIONS

By exposing tuna to wind turbine low frequency noise, main reactions are shown to high levels and longtime exposures. These reactions can be summarize as: i) position change in the water column of the fish school, ii) contraction of the school (avoidance) , iii) slight disorientation of some specimens and iv) increased speed.

This behavior was repeatedly observed with longtime emission in absence of other noise sources, and emission levels ~165 dB $_{\mathrm{ref}\ 1\mu Pa}$. By the behaviour shown during short time exposure, tuna seems to exhibit a high degree of adaptability.

In spite that the study clearly shows the Bluefin tuna reaction to turbine noise, the implications of this behaviour alteration is far to be still clear. The study was limited in time by economic reasons, but more exhaustive events should to be recorded and analysed for a complete characterization of effect of turbine noise on tuna. Finally, we cannot forget that we work with semicaptive animals which have not the same constraints that tuna in nature, they are limited in space and habituated to shipping traffic noise.

The effect of new human activities at ocean on ecosystems can only be measured more specific studies of affected species in each geographical area, improving the knowledge of physiology and behaviour, and developing methodologies and tools for studying and monitoring, and research in this line is needed.

This work was financially support from Spanish Government by grant AP2009-4459. We thank both personal and material facilities provided by Grup Balfegó and *Nuevo Tomás y Carmen* crew.

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